# COMPARATIVE ANALYSIS OF TECHNICAL, ECONOMICAL AND ENVIRONMENTAL FEASIBILITY OF COGENERATION PLANT USING WOOD BIOMASS

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## ABSTRACT

*After having identified, in a previous work [6], the possible sites for the location of a new cogeneration plant using wood biomass in the Mountain Community of Carnia, Friuli Venezia Giulia Region (Italy), the technical and economic feasibility and environmental sustainability of such a system has been carried out in order to evaluate the feasibility of the proposed solution.*

*In this paper are presented:*
- *the design of a cogeneration plant and the district heating network serving the thermal loads;*
- *the economic evaluation of the investment among the alternative;*
- *the environmental sustainability of the cogeneration plant and the district heating network compared to the conventional systems.*

## 1. INTRODUCTION

The use of renewable energy sources is constantly increasing, also in compliance with the objectives defined by the COP 21. Among the different renewables energies, biomass plays an important role, thanks to its extensive and homogeneous distribution in the territory, with an overall $CO_2$ environmental impact close to "zero".

In the territory of the Carnia, Friuli Venezia Giulia region (Italy), which covers 72,655.4 ha, there is an under-utilization, management deficiency and accumulation of wood in the forests. To support the mountains economy, the use of biomass has to be promoted, with actions aimed at increasing the quality of production, improving the logistics and facilitate the supply of raw materials to fuel cogeneration plants.

Through the use of open source GIS (Geographic Information System) applications and DBMS (Data Base Management System). numerous geographic layers belonging to the interested area have been analyzed: public and private users locations, existing electrical and roads infrastructure, existence, construction or design of thermal power plants and industrial activities and the availability of forest biomass wood establishing the feasibility of the forest-wood-central supply chain.

All data have been processed in order to make them consistent to respect to each other and produce the demand and energy supply maps. Adding the pattern of roads, the two best locations of a new cogeneration plant fuelled by biomass wood, have been identified, using a rating index and excluding the location of Arta Terme, where a similar plant has already been located [6].

The two potential sites are:

- place Vinadia - Villa Santina (former composting plant of municipal solid waste), which is in good position (isolated from the town of Tolmezzo) and well connected to the road network;
- location of the industrial area of Villa Santina (industrial warehouse former Marconi).

To carry out the study of technical and economic feasibility and environmental impact of a CHP system is essential to know the availability of woody biomass, the management program, the characteristics of the catchment area of the heat demand, especially with regards to weather conditions peculiar to the site and to the type of programs operating the utilities, investment and management costs, also taking into account the incentive systems and the withdrawal of energy into the network.

## 2. TECHNICAL FEASIBILITY OF THE ANALYZED SYSTEM SOLUTION

The realization of a heating system fueled by wood biomass requires, as a prerequisite, to dispose of sufficient quantities to ensure a regular supply of fuel [3]. Therefore, the feasibility of each project concerning energy utilization of biomass depends on the availability of raw material and its proper management [4]. A critical aspect related to the biomass supply is the consumption of primary resources with consequent emissions. Guidelines lead to the use of biomass in short distances (less than 70-80 km) to reduce the energy consumption required for transportation [2].

According to the Carnia 2009 energy plan, the average potential production of forest retractable biomass, for which the ordinary intervention is cost-effective, is 15,906 $m^3$, corresponding to 13,800 t/year [5]. The existing power plants, powered by wood biomass, use 13,368 t/year of wood chips mainly imported from outside the Region, of which only 1,337 t/year retractable directly from the Carnia's woods. Therefore 12,463 t/year are available for new projects. Considering the two locations identified in [6], three alternatives have been analyzed at preliminary plan level and described in the following.

Based on the study of Tolmezzo urban pattern, the central and south-west area of the town was chosen for district heating, because the old town presents difficulties in the installation of pipelines, given the type of buildings and the small size of the roadways. For this area two project alternatives have been identified:

1) district heating of the existing public buildings (data were taken from the Municipal Technical Office supplemented by a detailed study on energy consumption for the buildings under municipal management, at the owner Entity for the others) and private buildings with

a power rating greater than 116 kW (powers were derived from Provincial Firemen Command data; on the basis of similar installations, the specific winter and summer consumptions have been computed);

2) district heating in existing public and private buildings evaluating the power required according to their volumes, obtained from the Regional Numerical Technical Map, multiplied by the specific heat load of 30 W/m$^3$ calculated as the average of the available data collected for plants with nominal power greater than 116 kW. For the energy needs the values already acquired concerning the specific consumptions in winter and summer, have been used.

For Villa Santina (alternative 3), district heating is foreseen both for public utilities, then for private ones, including the industrial buildings. The power demands and energy requirements were determined like for the alternative 2 (Tolmezzo).

The climate profiles of Tolmezzo (altitude 323 m above mean sea level) and Villa Santina (363 m) show temperatures of respectively 3,036 and 3,109 degree days with a design outdoor temperature for the heating plants of -12°C; they belong to the climate zone F (D.P.R. 412/1993), where the thermal plants operation service don't foresee any restrictions for the heating period and the daily duration of activation. On the basis of the acquired climatic data, it was found that the average days of winter heating (24 hours a day) are 200 to which the days of partial heating need to be added, giving in total 5,200 hours of annual heating.

## 2.1 Alternative 1: technical feasibility

The analysed public utilities (hospital, swimming pool, gyms, schools, court etc.), all fuelled by methane, have an power of 19.8 MW, with a heating requirements during winter (from November to March, corresponding to 2,354 degree/day) and summer respectively of 10,185 MWh and 4,367 MWh. The analyzed private users, with single installed power rating greater than 116 kW, amount to 6.2 MW. Based on the specific consumption of similar plants with analogous meteorological characteristics, the winter and summer power needs have been calculated: 5,627 MWh and 2,312 MWh. Moreover, taking into account the users simultaneity coefficient, the power losses of the distribution system, the oversizing of existing thermal plants and the possible building expansion in the study area, an overall reduction of the computed theoretical power of 17% has been estimated, corresponding to a total power of 21.6 MW for the plant to be realized. In total for the two types of users, the total annual requirement is 22,491.0 MWh. Considering the trend of the outdoor temperature, the service hours and the needs required by public and private users, the time curve of the power required at the plant entrance in function of operating hours, has been calculated (Fig. 1).

In the same figure is shown the power of the cogeneration plant with turbine superheated steam fed to forest biomass chosen equal to 4.1 $MW_t$, which foresees the production of electrical energy at a power of 999 $kW_e$, with an estimated wood chips consumption of 10,108 t/year.

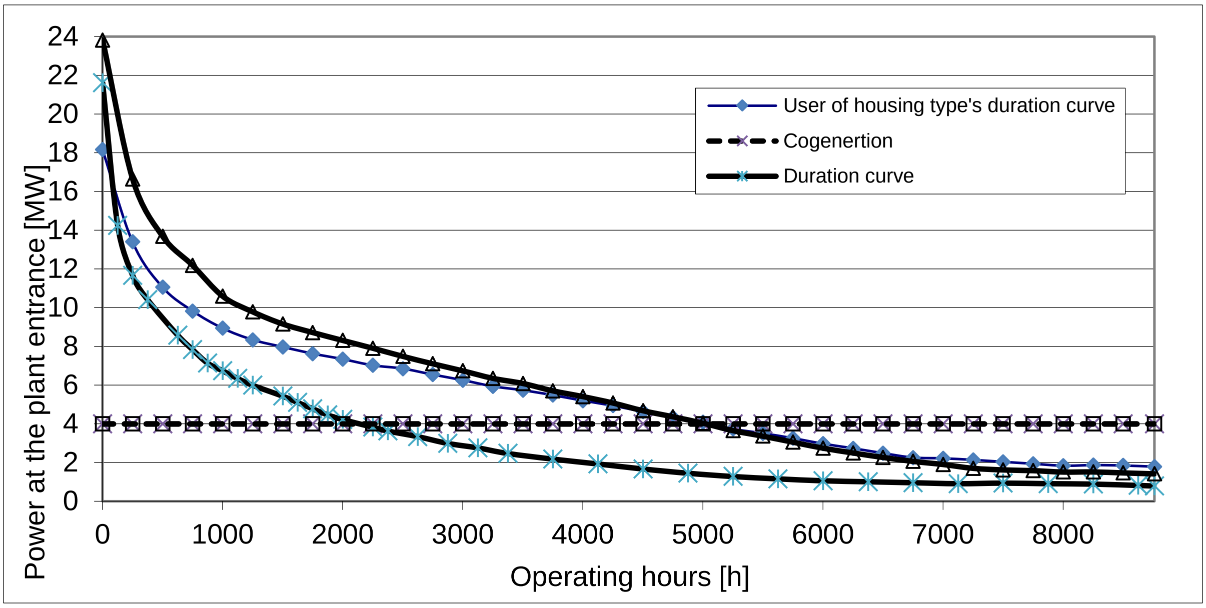


Fig.1 The time curve of the power required at the plant entrance

It can be noted that the intervention of the integration plant takes place only for 2,270 hours per year, being the curve lower than the other curves in similar plants; this is due to the fact that the analyzed public users consumption, with a potential triple of the private, has a limited daily functioning. The performed computations show an annual heat integration requirement for the connected users, of 8,840.0 MWh, inclusive of losses in the network.

The integration and reserve plant of the thermal energy will not be realized in location Vinadia, that is 2.56 km far away from Tolmezzo, but adjacent to the urban district heating. The plant will be realized in a new building with three generators, each with a heat power capacity of 9 $MW_t$ completed by pumping units and auxiliary components to feed the district heating network. The district heating network, suitably isolated, is located underground. Its path, apart from the connection between the cogeneration plant and the integration plant which runs along a main road, is located in the territory of the served users, branched along the existing streets.

The preliminary sizing of the network gave the following values: supply water temperature: 90°C, return water temperature: 70°C, length of the urban network: 9,938 m, length of the connecting pipe between the cogeneration plant and the integration and reserve plant plant: 2,560 m, nominal diameter of the pipe connecting the cogeneration plant and the integration lant and reserve: 200 mm, nominal diameter of the first tract of the urban network: 400 mm, pressure drop of the network connection between the cogeneration plant and the integration and reserve plant: 99.6 kPa, while in the urban network will have a maximum pressure drop of 511.0 kPa and supply water temperature of 89.1°C, in the most disadvantaged point of the urban network.

If the wood chips have a moisture content of 30%, the calorific value is equal to 3.4 kWh/kg (deciduous), and the plant functions for 8,592 hours per year (the period of maintenance of the plant is 1 week), the amount of biomass consumed will be 10,108 t/year, taking into account both the biomass retractable from Carnia's forest and from the neighbouring ones, than the one coming from the industrial production.

The annual consumption of natural gas that fuels the integration plant will amount to 886,957 $Nm^3$.

## 2.2 Alternative 2: technical feasibility

The public and private users served by the district heating network, located in the southwest of Tolmezzo, require a served power of 21.9 $MW_t$, which decreases to 18.1 $MW_t$ considering the predicted contemporary coefficient.

Calculations made on the basis of the civil users' needs, showed a private users requirement of 15,492.4 MWh during winter and 6,365.5 MWh in summer, and a public users requirement of 2,525.7 MWh in winter and 1,082.9 MWh in summer, corresponding to a total annual requirement of 25,466.5 MWh.

Similarly to the alternative 1, the Fig. 2 shows the time curve of the power required at the plant entrance in function of operating hours. This alternative foreseen the same cogeneration plant with superheated steam turbine of the alternative 1, positioned in location Vinadia. In the same Figure it can be seen that the integration plant works for 5,059 hours per year, with an annual heat integration requirement of 10,883.0 MWh, to be given to the connected users, inclusive of losses in the network. Such plant is placed in the same location of the alternative 1 and is provided with 3 heat generators with a power capacity of 7 $MW_t$.

The district heating network is similar to the one of the alternative 1 with different track branched, due to the different connected users.

The sizing of the foreseen network gave the following values: supply water temperature: 90°C, return water temperature: 70°C, length of the urban network: 13,227 m, length of the connecting pipe between the cogeneration plant and the integration and reserve plant: 2,560 m, nominal diameter of the pipe connecting the cogeneration plant and the integration and reserve plant: 200 mm, nominal diameter of the first tract of the urban network: 400 mm, pressure drop of the network connection between the cogeneration plant and the integration and reserve plant: 99.6 kPa, while in the urban network it will have a maximum pressure drop of 612.2 kPa, and supply water temperature in the most disadvantaged urban network point of 88.4°C.

The consumed wood chips quantity is the same of the alternative 1, while the annual methane consumption for the integration plant is equal to 1.09194 million $Nm^3$.

## 2.3 Alternative 3: technical feasibility

Public and private users, both civil than industrial, served by Villa Santina district heating network, require a power of 28.5 $MW_t$, decreased to 23.6 $MW_t$ taking into account the foreseen contemporary coefficient. The computation of thermal needs for civil and industrial users (public and private) provide: a need of 12,842.3 MWh during winter and 5,276.5 MWh during summer for private civil users; respectively 1131.7 MWh and 485.2 MWh for public civil users, and 6,357.9 MWh and 4,609.0 MWh, for industrial users, corresponding to a total annual requirement of 30,702.6 MWh.

The Fig. 2 shows the time curve of the power required at the plant as a function of operating hours.

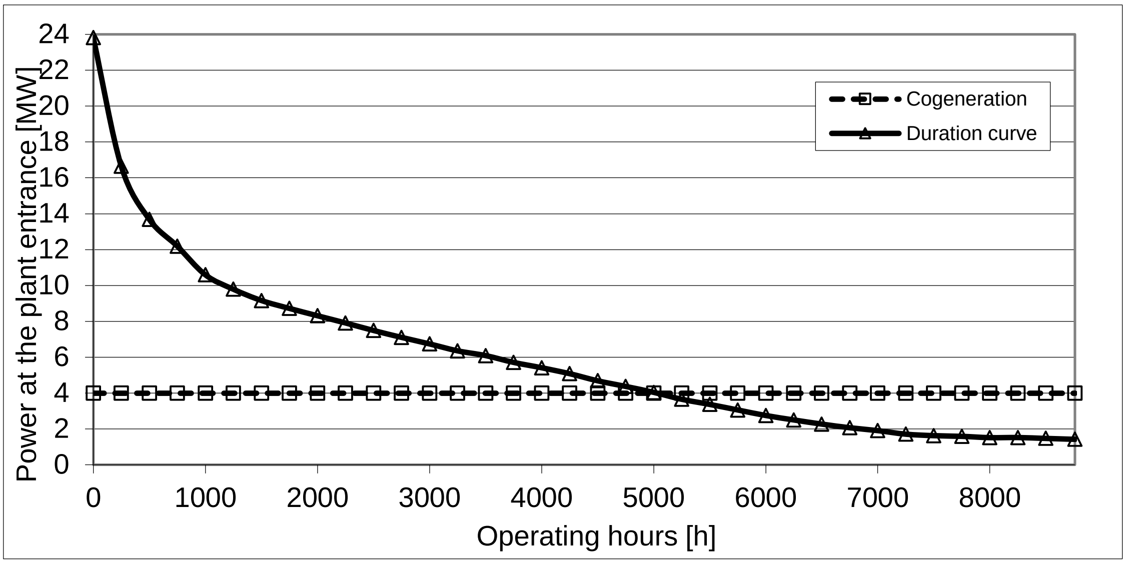


Fig.2

This alternative foreseen the placement of the cogeneration plant with overheated steam turbine and integration plant, in the same building, located in an industrial building no longer used. The cogeneration plant will have a power of 4 MWt, while the installation of integration plant will consist of three heat generators each with a power capacity of 10 $MW_t$. From Fig. 2 it is noted that the intervention of the integration plant is done for 5,031 hours per year, with an annual heat integration need of 12,501.0 MWh to be given to the connected users, inclusive of losses in the network. The district heating network has a path imposed by the distribution users to be served in the Villa Santina inhabited territory and runs along the existing roads with a branched configuration.

The sizing of the foreseen is: supply water temperature: 90°C, return water temperature: 70°C, length of the urban network: 14,144 m, nominal diameter of the first tract of the urban network: 400 mm, pressure drop of the network: 99.6 kPa, while in the urban network will have a maximum pressure drop of 723.7 kPa, and supply water temperature in the most disadvantaged urban network point of 89.2°C.

The consumed wood chips quantity is the same of the alternative 1, while the annual methane consumption for the integration plant is equal to 1,254,281 million $Nm^3$.

## 3. ECONOMIC FEASIBILITY OF THE ANALYZED SYSTEM SOLUTION

The economic analysis of the investment is based on the use of the net present value method (NPV), which also gives the payback period of the investment. For its determination the following items have been identified:

a) alternative 1

a1) investment related to the construction of the cogeneration plant with a superheated turbine steam which produces 4,095 kWt and 999 kWe, subdividing it in cost of construction works (purchase of the land, excavation, foundations, paving and connection to water and sanitation network, construction of a building for the cogeneration plant, offices, toilets and a control room) and cost of the electromechanical works (preparation section of the wood chips, cogeneration plant with a superheated turbine steam powered by biomass and fume treatment plant (sleeve filter and reactor at foam), corresponding to 6,065,000 €;

a2) investment for the integration plant fuelled by gas dividing it in cost of construction (purchase of the land, excavation, foundations, paving and connection to water and sewage networks, construction of a building for the heating plant and road-building necessary for the completion and functioning of the system) and the cost of the heating plant (3 hot water boilers, group circulation pumps, pressurization system and expansion of the water treatment plant, electronic heat meters, chimneys, link to water and sanitation networks and the electrical plant) corresponding to 2.420.00 €;

a3) investment for the district heating network (supply and laying of pipes, valves, bends, T, junctions and derivations, civil works, user substations and unexpected) corresponding to 4,410,000 €;

a4) expected and unexpected technical costs, both equal to 5% of the investment, bringing the total investment to 14,184,500 €;

a5) annual depreciation according to D.M. 31.12.1989 and subsequent amendments and additions, which amounts to 1,138,110 € for the first year of operation of the plant;

a6) annual operating costs for personnel, equipment maintenance, consumables, overheads and insurance, disposal for waste and residues, purchase of forest biomass, emergency electricity contract, natural gas for the integration plant and electrical energy of the pumping system, relative to the first year, equal to 2,918,260 €;

a7) revenues from the sale of electricity produced at the Energy Services Manager (GSE), sale of thermal energy to the users served by the district heating and the tariffs for the production of electricity from forest biomass (for 20 years) and sale of the Energy Efficiency Certificates (TEE) (for 15 years), relative to the first year of operation, equal to 3,911,972 €;

a8) taxes arising from the taxation of corporate income tax (IRES) and taxes from the regional production activities (IRAP) corresponding to 31.4% of gross profit;

a9) source of financing divided into equity (40%) and bank loan (60%), while it excludes the possibility of using capital grants;

a10) investment period 20 years;

a11) prime rate adopted 3.39%;

a12) 2% rates adjustment on the basis of inflation expected by the European Central Bank (ECB).

By applying the NPV method, a negative value of € 3,591,553 has been obtained, which does not permit the recovery of the investment even at the end of the period of the technical life of the plant (Fig. 3);

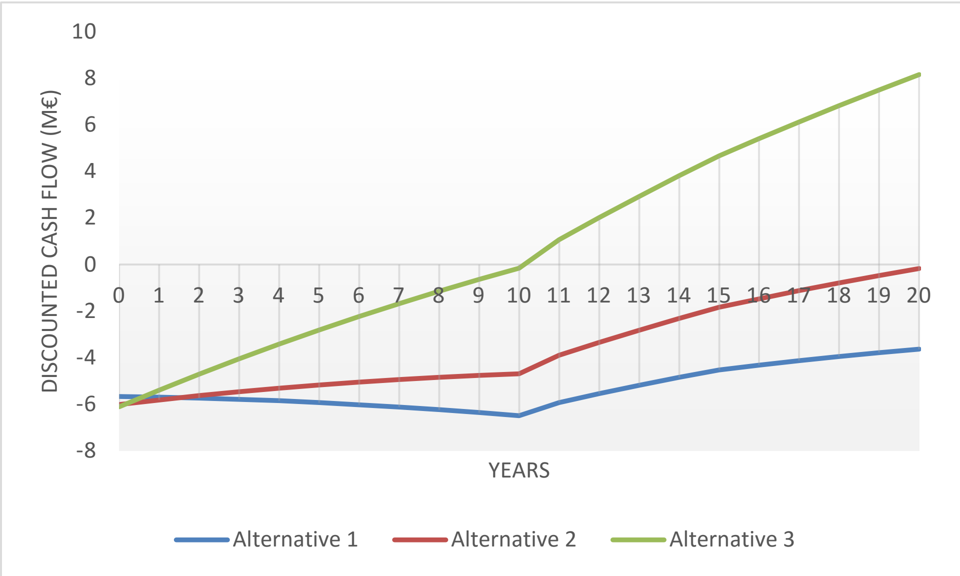


Fig.3. Performance of the discounted cash flow in the years of the three alternatives

b) alternative 2

Is set out below items which change to respect to the alternative 1:

a3) investment for the district heating network corresponding to 5,420,000 €;

a4) total investment of 15,031,500 €;

a5) annual depreciation, for the first year of operation of the plant it amounts to 1,209,000 €;

a6) annual operating costs, relative to the first year, equal to 2,997,755 €;

a7) revenues, relative to the first year of operation, equal to 4,228,865 €;

By applying the NPV method, a negative value of 176,376 € has been obtained, which does not permit the recovery of the investment even at the end of the period of the technical life of the plant (Fig. 3);

c) alternative 3

Is set out below items which change to respect to the alternative 1:

a1 & a2) cost of purchasing and adjustment of the industrial building used both for the cogeneration plant than for the integration plant and related electromechanical works corresponding to 8,492,000 €;

a3) investment for the district heating network corresponding to 5,400,000 €;

a4) total investment of 15,281,200 €;

a5) annual depreciation - for the first year of operation of the plant it amounts to 1,219,356 €;

a7) revenues, relative to the first year of operation, equal to 5,047,044 €;

By applying the NPV method, a positive value of 8,157,512 € has been obtained, which provides the recovery of the investment in slightly above 10th year of the plant's life (Fig. 3).

## 4. ENVIRONMENTAL SUSTAINABILITY OF THE ANALYZED SYSTEM SOLUTIONS

Regulated by the ISO 14040 and ISO 14044, the Life Cycle Assessment is used to determine the level of emissions for all phases of the product cycle. In the absence of reliable data on some processes, the evaluations of annual emissions of carbon dioxide ($CO_2$) of the cogeneration plant powered by wood biomass with district heating network and its transport to the plant and the ones of conventional systems with boilers fired by gas, have been compared. The cogeneration plant fuelled by wood chips, during the operating phase, produces emissions which must be added to those of the integration plant fuelled by methane. In particular, the annual emissions of $CO_2$ are:

a) for the co-generation plant fuelled by wood chips and the district heating network with integration plant fuelled by methane $E_{CO_2,year}$ :

$$E_{CO_2,year} = F_{e,biomass} \cdot e_{CO_2,biomass} + F_{e,methane,int} \cdot e_{CO_2,methane,int} + L_{average} \cdot n_{average} \cdot e_{CO_2,L}$$

where:

$F_{e,biomass}$ = annual energy need supplied by the cogeneration plant fuelled by wood biomass ($kWh_t$);

$e_{CO_2,biomass}$ = specific emissions of $CO_2$ from cogeneration plant fuelled by wood biomass =16 g/$kWh_t$ [Bot08];

$F_{e,methane,int}$ = annual energy need supplied by the integrative plant fuelled by methane ($kWh_t$);

$e_{CO_2,methane,int}$ = specific emissions of $CO_2$ by the integrative plant fuelled by methane = 124 g/$kWh_t$ [Bot08];

$L_{average}$ = average length of transportation (round trip) = 70 km;

$n_{average}$ = average number of transport of wood chips per year = 316;

$e_{CO_2L}$ = specific emissions of $CO_2$ from heavy vehicle with three axes for a maximum weight of 24 tonnes with vehicle weight of 4,5 t Euro type III/1999/96/EC [www.arpa.emr.it] = 1.020 g/km;

b) for traditional plants with boilers fuelled by methane $E_{CO_2,year}$ :

$$E_{CO_2,year} = F_{e,methane} \cdot e_{CO_2,methane}$$

where:

$F_{e,methane}$ = annual energy need required by the buildings ($kWh_t$);

$e_{CO_2,methane}$ = specific emissions of $CO_2$ from fired boilers fuelled by methane for buildings = 252 g/$kWh_t$ [Bot08].

Taking into account that the cogeneration plant in the three alternatives has the same potential and consumption of wood chips, it was assumed that the transport of biomass by the withdrawal areas to the plant is the same and therefore it is:

Annual emissions are:

a) alternative 1

- with the cogeneration plant fuelled by forest biomass and integrative plant fuelled by methane
  $F_{e,biomass}$ = 13,651 $MWh_t$
  $F_{e,methane,int}$ = 8,840 $MWh_t$

$$E_{CO_2,year} = \frac{13{,}651 \cdot 16}{1{,}000} + \frac{8{,}840 \cdot 124}{1{,}000} + 22{,}54 = 1{,}337.1\ t_{CO_2}/year$$

- with traditional plants fuelled by methane
  $F_{e,methane}$ = 22,491 $MWh_t$

$$E_{CO_2,year} = \frac{22{,}491 \cdot 252}{1{,}000} = 5{,}667.7\ t_{CO_2}/year$$

The saving of $CO_2$ emissions per year is 4,330.6 $t_{CO_2}/year$

b) alternative 2

- with the cogeneration plant fuelled by forest biomass and integrative plant fuelled by methane
  $F_{e,biomass}$ = 14,633.5 $MWh_t$
  $F_{e,methane,int}$ = 10,833 $MWh_t$

$$E_{CO_2,year} = \frac{14{,}633{,}5 \cdot 16}{1{,}000} + \frac{10{,}833 \cdot 124}{1{,}000} + 22{,}54 = 1{,}600.0\ t_{CO_2}/year$$

- with traditional plants fuelled by methane
  $F_{e,methane}$ = 25,466.5 $MWh_t$

$$E_{CO_2,year} = \frac{25.466{,}5 \cdot 252}{1000} = 6{,}417.6\ t_{CO_2}/year$$

The saving of $CO_2$ emissions per year is 4,817.6 $t_{CO_2}/year$

c) alternative 3

- with the cogeneration plant fuelled by forest biomass and integrative plant fuelled by methane
  $F_{e,biomass}$ = 18,201.6 $MWh_t$
  $F_{e,methane,int}$ = 12,501 $MWh_t$
  $$E_{CO_2,year} = \frac{18{,}201.6 \cdot 16}{1{,}000} + \frac{12{,}501 \cdot 124}{1{,}000} + 22{,}54 = 1{,}863.9\ t_{CO_2}/year$$
- with traditional plants fuelled by methane
  $F_{e,methane}$ = 30,702.,6 $MWh_t$
  $$E_{CO_2,year} = \frac{30{,}702.6 \cdot 252}{1{,}000} = 7{,}737.1\ t_{CO_2}/year$$

The saving of $CO_2$ emissions per year is 5,873.2 $t_{CO_2}/year$.

The replacement of many fireplaces with the ones of the thermal plant, whether unique (case study of Villa Santina) or two separate (case study of Tolmezzo), carries inevitably at worsening the air quality at the local level of the plant, if the distance from the town allows a adequate dispersion of the pollutants with the result of a significant improvement of the air quality in the urban areas. In addition to $CO_2$, nitrogen oxides ($NO_x$), sulphur dioxide ($SO_2$), carbon monoxide (CO) and particulate matter are emitted are emitted. The Legislative Decree 152/2006 sets the limits to the hourly concentration ($NO_2$ = 500 mg/Nm$^3$, $SO_2$ = 200 mg/Nm$^3$, CO = 300 mg/Nm$^3$, particulate matter = 30 mg/Nm$^3$ e and volatile organic compounds VOC = 150 mg/Nm$^3$).
The cogeneration plant will adopt different abatement systems to reduce emissions of the fireplace:

- for particular matter: bag filter, which exhibit high separation efficiencies of both coarse and thin particles;
- for $SO_2$, $NO_x$ and VOC: catalytic reactor with structured support through foams and honeycomb;
- for CO: to convert it to $CO_2$, introducing some excess air in the system.

## 5. CONCLUSION

The maps of energy demand and supply, as defined in [6], which identify the possible locations of the cogeneration plants fuelled by wood biomass, through indexes rating obtained with the use of open source GIS (Geographic Information System) applications and DBMS (Data Base Management System), cannot be separated from the execution of the technical and economic feasibility and environmental sustainability. The proposed methodology in this paper allows to test different cogeneration plants localizations as identified above. The same shows that all the considered alternatives have a technical feasibility and permissible environmental sustainability. The economic feasibility permits to identify the solution globally acceptable, if an investor takes the risk of getting profits only after the tenth year of the realization of the cogeneration plant with the associated district heating network (see alternative 3). Fig. 4 shows both the graph of district heating network service of the inhabited of Villa Santina, that an indication of the location of cogeneration plant fuelled by wood chips and integration plant fuelled by methane.

The methodology presented in [6] and completed in this paper could be applied to analogous situations and in similar geographical contexts.

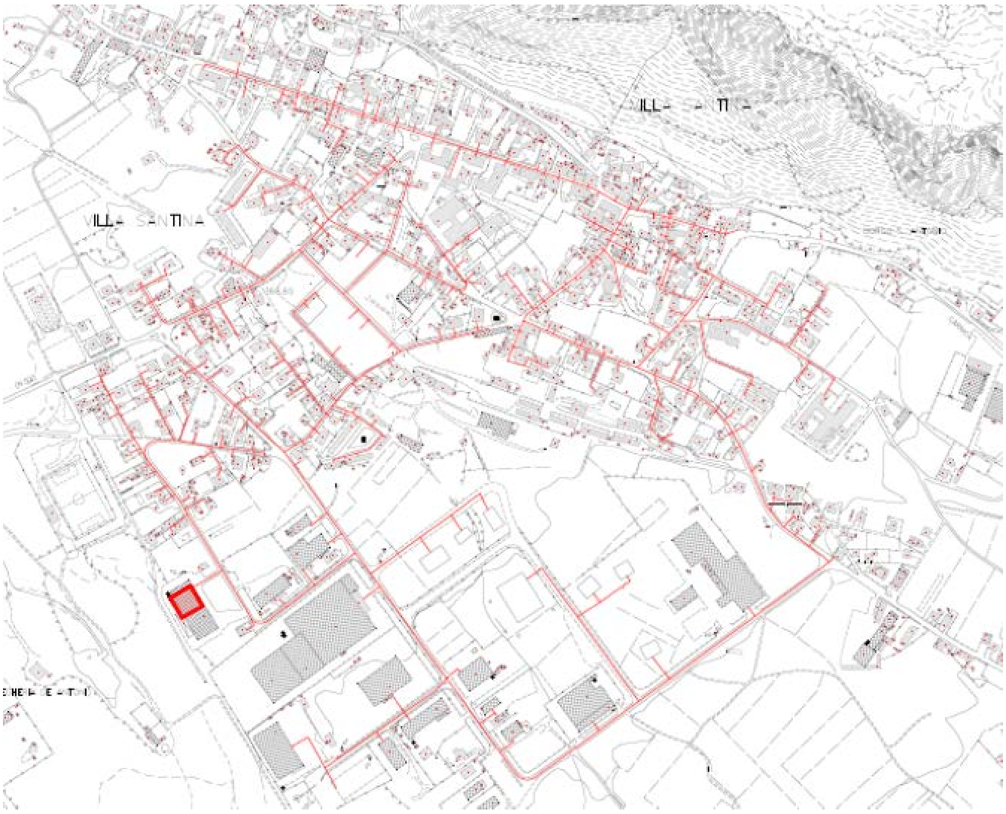

Fig.4. District heating network service of the inhabited of Villa Santina

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